

**CONTROLLER PERFORMANCE OF P, PI AND NEURAL NETWORK
CONTROL IN VINYL ACETATE MONOMER PROCESS**

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**A thesis submitted in fulfillment of the
requirements for the award of the degree of
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**Faculty of Chemical & Natural Resources Engineering
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I declare that this thesis entitled “Controller Performance of P, PI and Neural Network Control in Vinyl Acetate Monomer Process” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any degree.

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In the Name of Allah, Most Gracious, Most Merciful.

*All praise and thanks are due to Allah Almighty and peace and blessings be upon His
Messenger.*

To mum and dad, thanks for the love and support.

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ABSTRACT

This research is about investigating the controller performance between P, PI and Neural Network control in Vinyl Acetate Monomer (VAC) Process. The manufacturing process is about vapor-phase reaction converting ethylene (C_2H_4), oxygen (O_2) and acetic acid (HAc) into vinyl acetate (VAc) with water (H_2O) and carbon dioxide (CO_2) as byproducts. The data from the process are successfully generated and the simulation of the dynamic response is done with further analysis of P, PI control and Neural Network control. The study is focusing on the column section process as the clear view of the control performance is observed. The Proportional (P) and Proportional Integral (PI) control are type of controller that used in the process. The Neural Network control then is a control mechanism that has the similar system of human neurons for processing information data. It consists of network of neurons that have weight in each network and built generally in layers. As the analysis result of P and PI control showed that there are some unsatisfying results, Neural Network Control is then developed to see the changes. In Neural Network control, the data has been trained and validate to get the better response before applied again to the process to see the improvement. At the end, Neural Network has visualized the better control performance as the unsatisfying response of P and PI control have been improvised.

ABSTRAK

Kajian ini adalah untuk mempelajari perbezaan prestasi antara kawalan PID dan kawalan Hubungan Neural dalam contoh kes daripada proses penghasilan Vinyl Acetate. Proses reaksi fasa gas ini menghasilkan Vinyl Acetate (VAC) daripada ethylene (C_2H_4), oksigen (O_2) dan asid asetik (HAc) dan air (H_2O) serta karbon dioksida (CO_2) sebagai produk sampingan. Data daripada proses ini telah ditafsir keluar dengan baik dan simulasi dinamik respon dilakukan beserta analisis kontrol P dan PI dan juga kontrol hubungan neural. Kajian ini juga difokuskan pada bahagian proses pengasingan kolum untuk pemerhatian yang lebih jelas kepada prestasi kawalan. Kawalan P dan PI adalah kawalan yang digunakan di dalam proses ini. Kawalan Hubungan Neural pula adalah kawalan yang mirip kepada system tranformasi maklumat neurons manusia. Ianya mengandungi jaringan neuron dan berat tersendiri oleh setiap jaringan hubungan itu. Oleh kerana hasil analisis daripada kawalan P dan PI telah menunjukkan hasil yang kurang memuaskan, kawalan neural telah diimplimentasikan untuk melihat sebarang perubahan. Pada akhir kajian, kawalan neural telah menunjukkan bahawa hasil kawalan itu dapat diperbetulkan dan seterusnya melihatkan keberkesanan kawalan neural berbanding kawalan P dan PI.

TABLE OF CONTENT

CHAPTER	TITLE	PAGE
	TITLE PAGE	iv
	DECLARATION	v
	DEDICATION	vi
	ACKNOWLEDGEMENT	vii
	ABSTRACT	viii
	ABSTRAK	ix
	TABLE OF CONTENT	x
	LIST OF TABLES	xii
	LIST OF FIGURES	xiii
	LIST OF SYMBOLS	xv
1	INTRODUCTION	1
	1.1 Introduction	1
	1.2 Problem Statement	2
	1.3 Objectives of Study	2
	1.4 Scope of study	3
2	LITERATURE REVIEW	4
	2.1 The Vinyl Acetate Monomer (VAC) Process	4
	2.2 Feedback Control	6
	2.3 Block Diagram and Closed-Loop Response	8
	2.4 Proportional Integral Derivative (PID) Controller	10
	2.41 Effect on Proportional (P) Control	10
	2.42 Effect on PI control	13
	2.43 Effect on PID control	13
	2.5 Artificial Neural Network Control	14

3	METHODOLOGY	17
3.1	Overview	17
3.2	Work Flow	18
3.3	Data Generation	19
3.4	Specifying Column Section	20
3.5	Proportional (P) and Proportional Integral (PI) Control	21
3.6	Neural Network Control	21
4	RESULT AND DISCUSSION	23
4.1	Overview	23
4.2	Result for P control	24
4.3	Result for PI control	25
4.4	Disturbance Present of P control	26
4.5	Disturbance Present of PI control	27
4.6	The Identified Data	28
4.7	Training and Validation	29
4.8	Final Result of Neural Network Control	31
4.9	Comparison and Analysis	32
5	CONCLUSION AND RECOMMENDATION	34
5.1	Conclusion	34
5.2	Recommendation	35
	REFERENCES	36
	APPENDIX	38-44

LIST OF TABLES

TABLE NO.	TITLE	PAGE
4.1	Mean square error for validation and training of Vapor In (Vap-In)	29
4.2	Mean square error for validation and training Org. Level (Org-L)	31

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Vinyl acetate monomer process flowsheet	5
2.2	General process block diagram	6
2.3	Corresponding feedback loop	7
2.4	The general closed loop system	8
2.5	Closed loop response of setpoint changes	12
2.6	Closed loop response of disturbance change	12
2.7	Effect of gain on the closed-loop response with PID control	14
2.8	Single processing node	15
2.9	Neural Network Layer	15
3.1	Work flow diagram	18
3.2	Data Generation	19
3.3	Column section	20
3.4	Neural Network implementation and training	22
4.1	Result for P controller	24
4.2	Result for PI controller	25
4.3	Result for P controller with disturbance	26
4.4	Results for PI controller with disturbance	27
4.5	Vapor-In Response of P and PI control	28
4.6	Organic Level Response of P and PI control	28

4.7	Training and Validation for Vapor In (Vap-In)	29
4.8	Training and Validation for Organic Level (Org-L)	30
4.9	Final Result of Neural Network Control for Vapor In (Vap-In)	32
4.10	Final Result of Neural Network Control for Organic Level (Org-L)	32
4.11	Result of P and PI control for Vapor In (Vap-In)	32
4.12	Final Result of Neural Network Control for Vapor In (Vap-In)	32
4.13	Result of P and PI control for Organic Level (Org-L)	33
4.14	Final Result of Neural Network Control for Organic Level (Org-L)	33

LIST OF SYMBOLS

SYMBOLS / ABBREVIATION	TITLE
m	Manipulated variable
d	Potential disturbance
y	Output
y_m	Measured value
y_{sp}	Set point value
ϵ	Deviation error
G_p	Process
G_d	Disturbance
G_m	Measurement
G_c	Controller
G_f	Final Control Element
K_c	Gain
K'_p & K'_d	Closed-loop static gains
t	Time constant
t_d	Dead time

CHAPTER 1

INTRODUCTION

1.1 Introduction

In 1998, an additional model of a large, industrially relevant system, a vinyl acetate monomer (VAC) manufacturing process, was published by Luyben and Tyreus. The VAC process contains several standard unit operations that are common to many chemical plants. Both gas and liquid recycle streams are present as well as process-to-process heat integration. Luyben and Tyreus presented a plantwide control test problem based on the VAC process. The VAC process was modeled in TMODES, which is a proprietary DuPont in-house simulation environment, and thus, it is not available for public use (Luyben and Tyreus, 1998).

The model of the VAC process is developed in MATLAB, and both the steady state and dynamic behavior of the MATLAB model are designed to be close to the TMODES model. Since the MATLAB model does not depend on commercial simulation software and the source code is open to public, the model can be modified for use in a wide variety of process control research areas. For each unit, design assumptions, physical data, and modeling formulations are discussed. There are some differences between the TMODES model and the MATLAB model, and these differences together with the reasons for them are pointed out. Steady state values of the manipulated variables and major measurements in the base operation are given. Production objectives, process constraints, and process variability are summarized based on the earlier publication. All of the physical property, kinetic data, and process flowsheet information in the MATLAB model come from sources in the open literature.

The manufacturing process is about vapor-phase reaction converting ethylene (C_2H_4), oxygen (O_2) and acetic acid (HAc) into vinyl acetate (VAc) with water (H_2O) and carbon dioxide (CO_2) as byproducts. It has both gas and liquid recycle streams with real components. The process contain 10 basic unit operations that include a catalytic plug flow reactor, a feed-effluent heat exchanger (FEHE), a separator, a vaporizer, a gas compressor, an absorber, a carbon dioxide (CO_2) removal system, a gas removal system, a tank for the liquid recycle stream and an azeotropic distillation column with a decanter plants (Luyben and Tyrus, 1997). This process is focusing the data response of the column section to give the clear view of the controller performance. The control response of P, PI and Neural Network controller is observed for further analysis.

1.2 Problem Statement

Generally, the actual data of Vinyl Acetate Monomer (VAC) process is controlled by either P or PI control. The suitability using Neural Network Control alongside the actual P and PI control and the capability of the controller to improve the unsatisfied result is investigated and analyzed.

1.3 Objectives of Study

The aims of this study are:

To generate data the of control process in Vinyl Acetate Monomer (VAC) besides investigating the controller performance of PI and P control compared to Neural Network controllers in Vinyl Acetate Monomer (VAC) process.

1.4 Scope of Study

In order to achieve the objectives, the study is specified into those scopes:

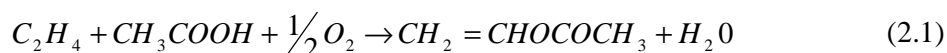
- a) To generate data from Vinyl Acetate (VAC) monomer process
- b) To simulate dynamic response of the data.
- c) To analyze the performance of the controller response of P, PI control and Neural Network control.
- d) To analyze and compare the performance of the controllers.

CHAPTER 2

LITERATURE REVIEW

2.1 The Vinyl Acetate Monomer (VAC) Process

The vinyl acetate monomer (VAC) manufacturing process consist 10 basic unit operation which include catalytic plug flow reactor, a feed-effluent heat exchanger (FEHE), a separator, a vaporizer, a gas compressor, an absorber, a carbon dioxide (CO₂) removal system, a gas removal system, a tank for the liquid recycle stream and an azeotropic distillation column with a decanter plants (Luyben and Tyrus, 1997). The manufacturing process is about vapor-phase reaction converting ethylene (C₂H₄), oxygen (O₂) and acetic acid (HAc) into vinyl acetate (VAc) with water (H₂O) and carbon dioxide (CO₂) as byproducts. An inert, ethane (C₂H₆), enters with the fresh ethylene feed stream. The reactions are as below:



The exothermic reactions occur in a reactor containing tubed packed with precious metal catalyst on a silica support. Heat is removed from the reactor by generating steam on the shell side of the tubes. Water flows to the reactor from a steam drum, to which make-up water (BFW) is provided. The steam leaves the drum as saturated vapor. The reactions are irreversible and the reaction rates have an Arrhenius-type dependence on temperature.

Figure 2.1 shows the process flow sheet with location of the manipulated variables. The numbers on the streams are the same as those given by Luyben and Tyreus (1997).

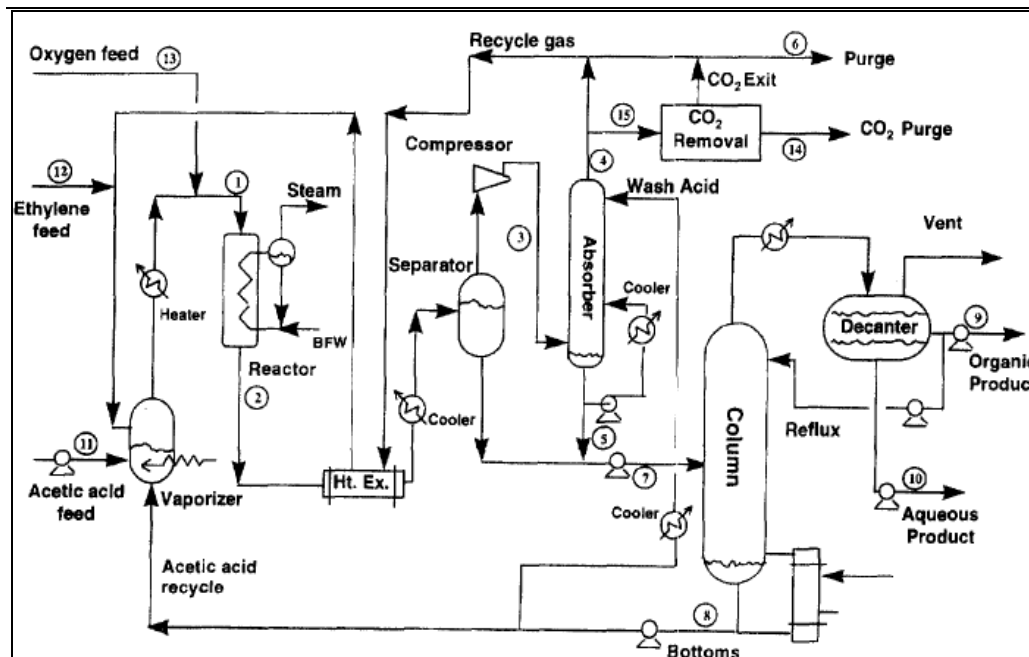


Figure 2.1: Vinyl acetate monomer process flowsheet

The reactor effluent leaves through a process-to-process heat exchanger, where the cold stream is the gas recycle. Then, the effluent is cooled with cooling water and the vapor (oxygen, ethylene, carbon dioxide and ethane) and liquid (vinyl acetate, water and acetic acid) are separated. The vapor stream from the separator goes to the compressor and the liquid stream from the separator becomes a part of the feed to the azeotropic distillation column. The gas from the compressor enters the bottom of an absorber, where the remaining vinyl acetate is recovered. A liquid stream from the base is recirculated by a cooler and fed to the middle of the absorber. To provide scrubbing, the liquid acetic acid that has been cooled is fed into the top of the absorber. The liquid bottoms product from the absorber combines with the liquid from the separator as the feed stream to the distillation column (Luyben and Tyreus, 1997).

Some of the overhead gas exiting the absorber enters the carbon dioxide removal system is simplified by treating it as component separator with a certain

efficiency that is a function of rate and composition. The gas stream minus carbon dioxide is split, with part going to the purge for removal of the inert ethane and the rest combines with large recycle gas stream goes to the feed-effluent heat exchanger also with added fresh ethylene feed stream. Steam is used to vaporize the liquid in the vaporizer where the gas recycle stream, the fresh acetic acid feed and the recycle liquid acetic acid enters. The gas stream from the vaporizer is further heated to the desired reactor inlet temperature in a trim heater using steam. To keep the oxygen composition in the recycle loop outside the explosives region, fresh oxygen is added to the gas stream from the vaporizer.

The azeotropic distillation column then separates the vinyl acetate and water from the unconverted acetic acid. The overhead product is condensed with cooling water and the liquid goes to the decanter, where the vinyl acetate and water phase separate. The bottom product from the distillation column contains acetic acid, which recycles back to the vaporizer along with fresh make-up acetic acid. Part of this bottom product is the wash acid used in the absorber after being cooled (Mc Avoy, 1998).

2.2 Feedback Control

In general process, feedback control process has an output y , a potential disturbance d , and an available manipulated variable m . (George Stephanopoulos, 2004). The process is shown in Figure 2.2 below:

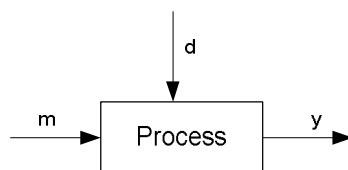


Figure 2.2: General process block diagram

The disturbances, d or load change is an unpredictable manner and the aim of the control process is to keep the value of the output, y at the desired levels. A feedback control action takes the following steps. First, the value of the output (flow,

pressure, liquid level, temperature, composition) will be determined using the appropriate measuring device with y_m be the value indicated by the measuring sensor. Then, the indicated value y_m is compared to the desired value y_{sp} (set point) of the output and the deviation (error) would be $e = y_{sp} - y_m$. The value of the deviation e is supplied to the main controller. The controller in turn changes the value of the manipulated variable m in such way as to reduce the magnitude of the deviation e . Usually the controller does not affect the manipulated variable directly but through another device (usually a control valve), known as the final control element.

Figure 2.3 shows the notified steps. The system in Figure 2.2 is known as open loop, in contrast to the feedback controlled system in Figure 2.3 which is called closed loop. When value of d or m change, the response of the first step is categorized open loop response while the second step is the closed loop response.

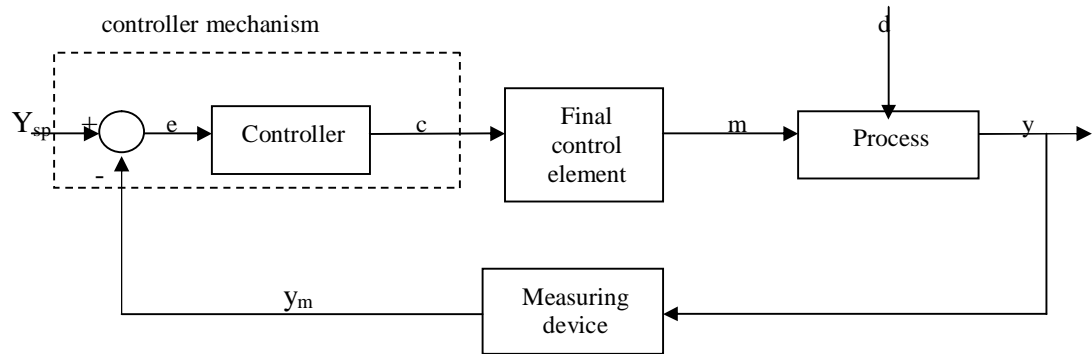


Figure 2.3: Corresponding feedback loop

2.3 Block Diagram and the Closed-Loop Response

For the generalized closed-loop system showed in Figure 2.4, it has four components (process, measuring device, controller mechanism and final control element) which corresponding transfer functions relating its output to the inputs can be written.

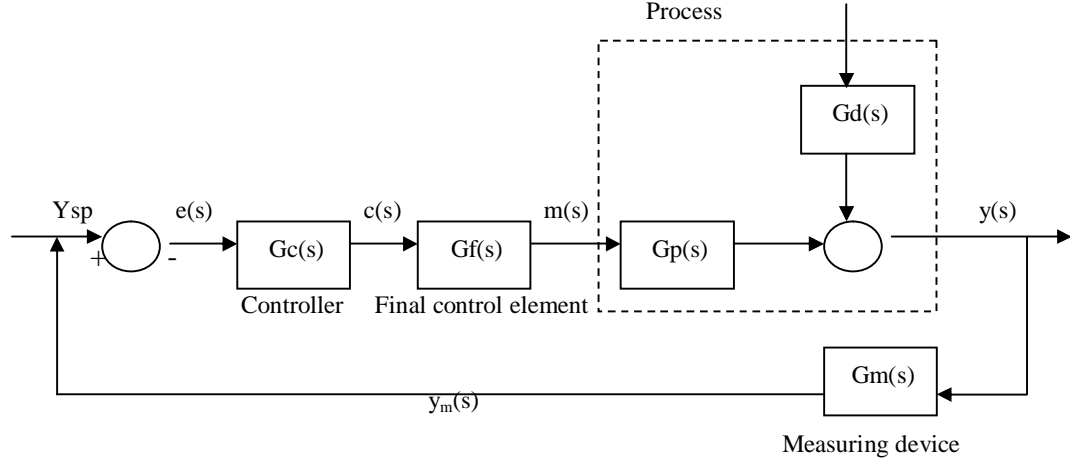


Figure 2.4: The generalized close-loop system

In particular, if the dynamics of the transmission lines, are neglect:

Process:

$$\bar{y}(s) = G_p(s)\bar{m}(s) + G_d(s)\bar{d}(s) \quad (2.3)$$

Measuring device:

$$\bar{y}_m(s) = G_m(s)\bar{y}(s) \quad (2.4)$$

Controller mechanism:

$$\bar{\epsilon}(s) = \bar{y}_{sp}(s) - \bar{y}_m(s) \text{ comparator} \quad (2.5)$$

$$\bar{c}(s) = G_c(s)\bar{\epsilon}(s) \text{ control action} \quad (2.6)$$

Final Control Element :

$$\bar{m}(s) = G_f(s)\bar{c}(s) \quad (2.7)$$

where G_p, G_d, G_m, G_c and G_f are the transfer function between the corresponding inputs and outputs (McMillan, 1994). The series of blocks between the comparator and the controlled output (i.e., G_c, G_f and G_p) constitutes the forward path, while

the block G_m is on the feedback path between the controlled output and the comparator.

Algebraic manipulation of the equations above yields

$$\bar{m}(s) = G_f(s)G_c(s)[\bar{y}_{SP}(s) - G_m(s)\bar{y}(s)] \quad (2.8)$$

completing back the equation (2.3) give:

$$\bar{y}(s) = G_p(s)\{G_f(s)G_c(s)[\bar{y}_{SP}(s) - G_m(s)\bar{y}(s)]\} + G_d(s)\bar{d}(s) \quad (2.9)$$

and after readjusting

$$\bar{y}(s) = \frac{G_p(s)G_f(s)G_c(s)}{1 + G_p(s)G_f(s)G_c(s)G_m(s)} \bar{y}_{SP}(s) + \frac{G_d(s)}{1 + G_p(s)G_f(s)G_c(s)G_m(s)} \bar{d}(s) \quad (2.10)$$

This equation gives the closed-loop response of the process. It is composed of two terms. The first term shows the effect on the output of change in the set point, while the second term tells the effect on the output of a change in the load (disturbance). The corresponding transfer functions are known as closed-loop transfer functions. In particular,

$$\frac{G_p}{1 + GG_m} = G_{SP} \quad (2.11)$$

is the closed loop transfer function for a change in the set point and

$$\frac{G_d}{1 + GG_m} = G_{load} \quad (2.12)$$

is the closed loop transfer function for a change in the load.

2.4 Proportional Integral Derivate (PID) Controller

There are some type of controllers that can be used in the control system in order to get the observation of the step change in set point (set point tracking) and the step change in load (disturbance rejection). Among the type of controllers are proportional (P) control, proportional-integral (PI) control and proportional-integral-derivatives (PID) control.

2.4.1 Effect on Proportional (P) Control

As known, the closed-loop response of a process is given by equation (2.10). To ease the analysis assumption is made that:

$$G_m(s) = 1, \quad G_f(s) = 1 \quad \text{and} \quad G_c(s) = K_c \text{ (proportional controller)}$$

then the equation become

$$\bar{y}(s) = \frac{G_p(s)K_c}{1 + G_p(s)K_c} y_{SP} + \frac{G_d(s)}{1 + G_p(s)K_c} \bar{d}(s) \quad (2.13)$$

for first order systems yield

$$\bar{y}(s) = \frac{K_p}{t_p s + 1} \bar{m}(s) + \frac{K_d}{t_p s + 1} \bar{d}(s) \quad (2.14)$$

Then, for uncontrolled system, where

$$G_p(s) = \frac{K_p}{t_p s + 1} \quad \text{and} \quad G_d(s) = \frac{K_d}{t_p s + 1}$$

included in equation (2.13) and yield the closed-loop response:

$$\bar{y}(s) = \frac{K_p K_c}{t_p s + 1 + K_p K_c} \bar{y}_{SP}(s) + \frac{K_d}{t_p s + 1 + K_p K_c} \bar{d}(s) \quad (2.15)$$

readjust

$$\bar{y}(s) = \frac{K'_p}{t'_ps + 1} \bar{y}_{sp}(s) + \frac{K'_d}{t'_ps + 1} \bar{d}(s) \quad (2.16)$$

where

$$t'_p = \frac{t_p}{1 + K_p K_c}, \quad K'_p = \frac{K_p K_c}{1 + K_p K_c} \quad \text{and} \quad K'_d = \frac{K_d}{1 + K_p K_c}$$

K'_p and K'_d also known closed-loop static gains.

As the result the closed-loop response of a first order system is still is the first order system with respect to load and set point changes. The closed-loop response has become faster than the open-loop response to the change in set point or load, due to the time constant that has been reduced and also the static gains that have been decreased.

In order to get better observation to the effect of this proportional controller, the resulting closed-loop responses is reviewed and examined with set point and the disturbance changes.

For change in the set point where $\bar{y}_{sp} = \frac{1}{s}$ and $\bar{d}(s) = 0$, which insert to equation (2.16) resulting

$$\bar{y}(s) = \frac{K'_p}{t'_ps + 1} \frac{1}{s}$$

in the inverse mode give

$$y(t) = K'_p(1 - e^{-t/t'_p}) \quad (2.17)$$

Figure 2.5 view the response of the closed loop response to set point change. The ultimate response, after $t \rightarrow \infty$, never reaches the desired new set point. There is a discrepancy called offset which is equal to

$$\begin{aligned} \text{offset} &= (\text{new set point}) - (\text{ultimate value of the response}) \\ &= 1 - K'_p \\ &= \frac{1}{1 + K_p K_c} \end{aligned}$$

The offset is the effect of proportional control. It decreases as K_c becomes larger and generally

offset $\rightarrow 0$ when $K_c \rightarrow \infty$

For change in the disturbance, $\bar{y}_{sp}(s) = 0$ and $\bar{d}(s) = \frac{1}{s}$. Hence the equation (2.17)

become

$$\bar{y}(s) = \frac{K'_d}{t'_p s + 1} \frac{1}{s}$$

inverse give

$$y(t) = K'_d (1 - e^{-t/t'_p}) \quad (2.18)$$

Response in the disturbance change is shown in Figure 2.6. Again the proportional controller cannot keep the response at the desired set point but it exhibits an offset:

$$\begin{aligned} \text{offset} &= (\text{set point}) - (\text{ultimate value of response}) \\ &= 0 - K'_d \\ &= -\frac{K_d}{1 + K_p K_c} \end{aligned}$$

The advantage of the proportional control in the presence of disturbance changes, the response is much closer to the desired set point than not have control at all (Lee, 1998). This effect can be viewed from the Figure 2.6. If the gain K_c is increased the offset decreases and theoretically

offset $\rightarrow 0$ when $K_c \rightarrow \infty$

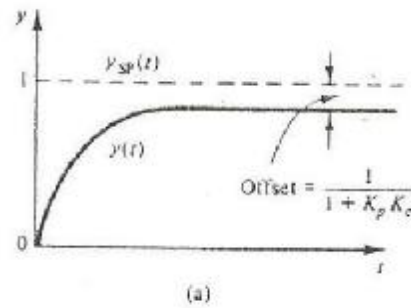


Figure 2.5: Closed-loop response of set point change

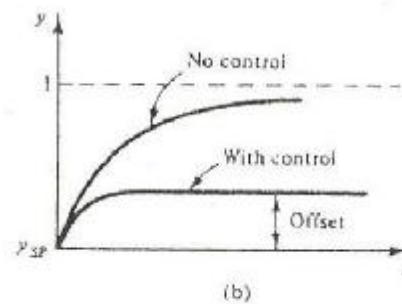


Figure 2.6: Closed-loop response of disturbance change